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Performance of Steel Fiber Reinforced Concrete Corbels

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***Abstract* - Seven full-scale reinforced concrete corbel specimens were tested to study performance of steel fiber reinforced concrete corbels with and without fibers were investigated. The test variables were steel fiber content (Vf %) and shear span-to-depth ratio (a/d), which Constants of concrete compressive strength (fcu), area of main steel reinforcement (As) and presence of horizontal stirrups. Test results showed that, addition of steel fibers or/and horizontal stirrups improves both shear strength and ductility of the tested corbels, and results in a more ductile failure mode. The Experimental results observed that the ultimate strength of reinforced concrete corbels along with fibers can be predicted by adding the fibers contribution to strength using the shear friction equation to the ACI Building Code provisions. It is found that considerable improvement in ultimate shear strength and first crack in the corbels. This study shows that there is a considerable increase in the ultimate shear strength of steel fiber reinforced concrete corbels is obtained by the addition of steel fibers for a specific range and with a fiber content of 1,2 and3 percent, an increase in the shear strength was obtained and decrease shear span to depth ratio from 0.80 to 0.65.**

Keywords: Fiber Reinforced Concrete, Steel Fibers, Shear Strength, Corbels, Horizontal Stirrups, Shear Span to Depth.

I. INTRODUCTION

Short cantilevers with a span to depth Ratio less than or equal one (Corbels) are becoming popular in reinforced concrete (RC) structures. Failure mode of corbels varies based on the following: (1) span to depth ratio; (2) type of loading; (3) concrete strength; (4) concrete dimensions; (5) longitudinal and transversal reinforcement. They could fail in shear or flexure, however, they are subjected to large shear forces, thus, commonly fail brittle in shear by splitting diagonal cracks. Such brittle failure is catastrophic and has to be avoid. Steel fiber reinforced concrete are being widely utilized in various civil engineering applications, thus, investigating the feasibility of enhancing the performance of RC corbels by using these materials, which can be added to the concrete mix in order to enhance the concrete performance, consequently, delaying the shear failure of the RC Corbels. Thus, the aim of this research is to study the behavior of R.C. corbels fabricated from (SFRC).

II. EXPERIMENTAL PROGRAMME

a) Test Material

Ordinary Portland cement CEM I 52.5 N was used. The coarse aggregate was crushed basalt with a maximum nominal size of 10 mm and 20 mm. The grade of concrete is Fcu30 with mix proportion of 1:1.95:3.65 by weight with water cement ratio of 0.43 was kept constant for all Specimens. Deformed bars of about 360 N/mm2 proof strength and having diameter 10, 12 mm were used as main bars and column compression bars. The stirrups used were made of 8 mm diameter smooth bars of 240 N/mm2 yield strength. Only one type of steel fibers -under a commercial name HAREX, made of steel having a minimum tensile strength of 400 N/mm2 was used. The fibers were of 50 x 0.9 mm dimensions, with hooked-ends, and aspect ratio equals 55.All used materials are agreed with ECCS 203.

TABLE I
The Constituent Materials

Compressive strength (Kg/cm^2)	Water ($Lit./m^3$)	Cement (Kg/m^3)	Sand (Kg/m^3)	Dolomite (Kg/m^3)
300	165	350	682.25	1275.80

b) Specimen Details

All specimens had identical concrete dimensions. The column had a rectangular cross section of 250 mm depth, 125 mm width and 1900 mm clear height while all cantilevers had a (R-cross section) all the test cantilevers had total depth of 300 mm start, 150 mm end and 300mm clear span from the

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column face. Figure (1) shows the concrete dimensions and the reinforcement details of a typical specimen in Table I.

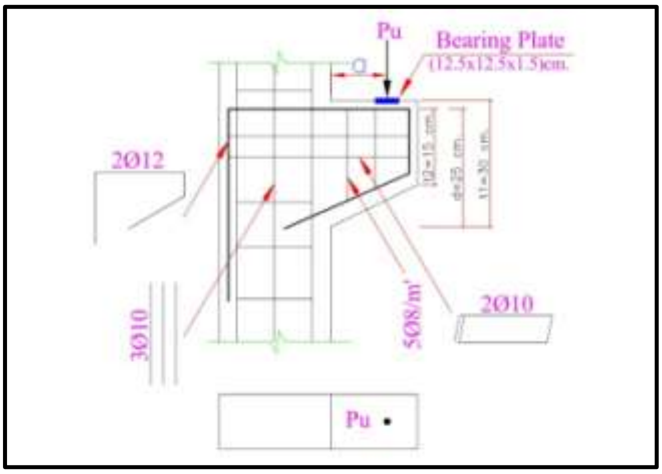

Figure 1: Concrete dimensions and reinforcement details of a typical specimen

TABLE II
Details of reinforcement for all specimens

Corbels No.	Compressive Strength F_{cu}(N/mm²)	V_f%	a/d	Corbels R.F.T			
				Main R.F.T		Stirrup	
				Upper	Lower	Vertical	Horizontal
C-0.80-0%	30	0.0	0.80	2Φ12	2Φ12	5Φ8/m'	2Φ10
C-0.80-1%	30	1.0		2Φ12	2Φ12	5Φ8/m'	2Φ10
C-0.80-2%	30	2.0		2Φ12	2Φ12	5Φ8/m'	2Φ10
C-0.80-3%	30	3.0		2Φ12	2Φ12	5Φ8/m'	2Φ10
C-0.75-2%	30	2.0	0.75	2Φ12	2Φ12	5Φ8/m'	2Φ10
C-0.70-2%	30		0.70	2Φ12	2Φ12	5Φ8/m'	2Φ10
C-0.65-2%	30		0.65	2Φ12	2Φ12	5Φ8/m'	2Φ10

III. TEST PROCEDURE AND MEASUREMENTS

A hydraulic testing machine with bearing capacity of 1500 kN was used. The load scheme adopted is shown in Figure 2. Corbels tested were supported symmetrically by one steel hinges placed at a distance (a) from the face of column as shown in Figure. 1. At each load incensement, vertical deflection of center of bottom surface of column, steel strain of main bar and concrete strain were recorded. Also for all corbels, the cracking load and the ultimate load are recorded while the patterns of crack propagation were observed.

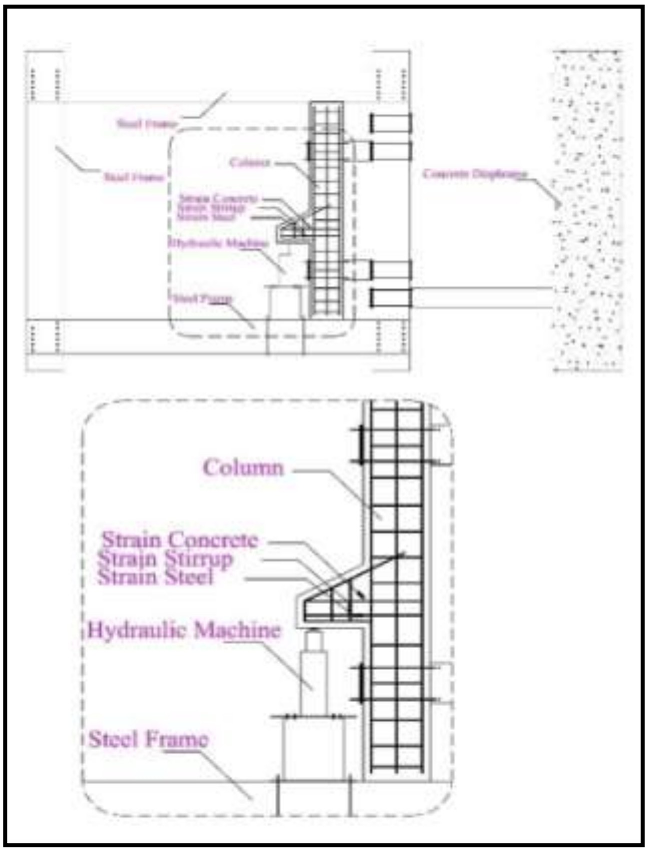

Figure 2: Test setup

IV. TEST RESULTS AND DISCUSSIONS

The first crack to appear was flexural crack starting at or near the column corbel interface and subsequent flexural cracks away from this section were formed. As this applied load increased, one of the flexural cracks in the shear span extended diagonally upward toward the corbel-column connection, or a diagonal crack formed at the mid height of the corbel within the shear span. After the formation of the diagonal cracks, corbels with higher volume of fibers or/and horizontal stirrups showed higher load carrying capacity. All corbels failed in shear and the failure was as follows. Finally, all corbels failed by the extension of the diagonal crack toward the corbel-column connection. The trend of cracking was almost the same, except that the number of the cracks appeared to depend on the fiber and/or horizontal stirrups content. Corbels without fibers, exhibited a sudden failure. It has to be mentioned that the presence of high percentage of either steel fibers and/or horizontal stirrups transformed the failure mode into a more ductile one and increased the number of the diagonal cracks formed. This indicates that steel fibers and/or horizontal stirrups became effective after shear cracks formed and continued to resist the principal tensile stress until failure occurred at one critical crack. However, increase in shear span-to- depth ratio transformed the failure mode to

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more ductile one and increased the number of the formed cracks

The below graph indicates load deflection curve for C-0.80-0%. Here the first crack occurs at load-50.0KN, deflection of 2.63 mm and the ultimate load is 110.15 KN with deflection of 5.80mm.Figure-3.

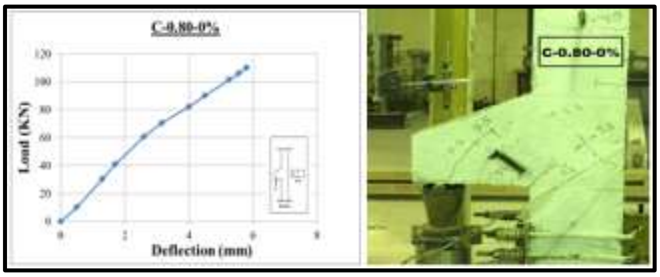

Figure 3: Specimen (C-0.80-0%)

The below graph indicates load deflection curve for C-0.80-1%. Here the first crack occurs at load-55.0KN, deflection of 3.08 mm and the ultimate load is 123.08 KN with deflection of 6.90mm.Figure-4

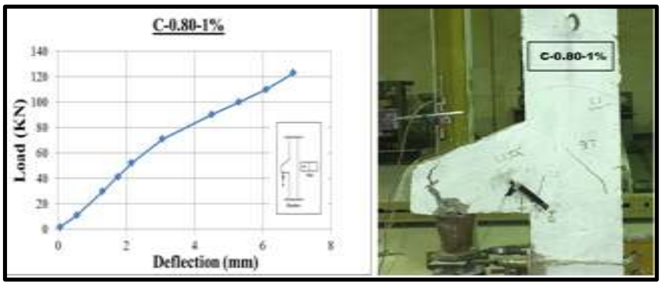

Figure 4: Specimen (C-0.80-1%)

The below graph indicates load deflection curve for C-0.80-2%. Here the first crack occurs at load-90.0KN, deflection of 3.52 mm and the ultimate load is 143.01 KN with deflection of 5.60mm.Figure-5

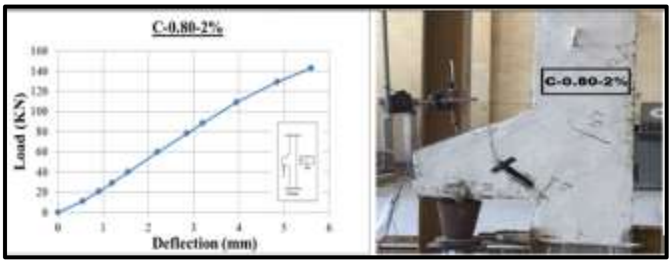

Figure 5: Specimen (C-0.80-2%)

The below graph indicates load deflection curve for C-0.80-3%. Here the first crack occurs at load-70.0KN, deflection of 4.14 mm and the ultimate load is 95.51 KN with deflection of 5.65mm.Figure-6

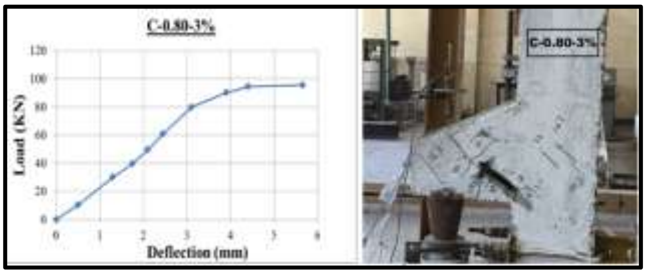

Figure 6: Specimen (C-0.80-3%)

The below graph indicates load deflection curve for C-0.75-2%. Here the first crack occurs at load-80.0KN, deflection of 4.15 mm and the ultimate load is 145.06 KN with deflection of 4.95mm.Figure-7

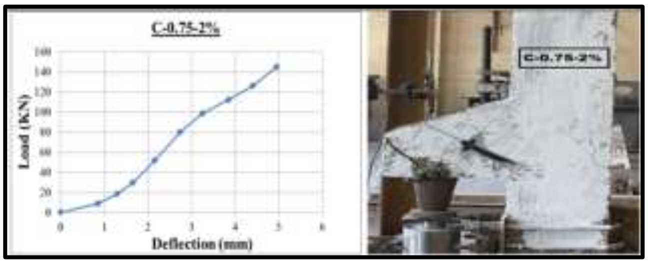

Figure 7: Specimen (C-0.75-2%)

The below graph indicates load deflection curve for C-0.70-2%. Here the first crack occurs at load-60.0KN, deflection of 3.29 mm and the ultimate load is 163.74 KN with deflection of 4.41mm.Figure-8

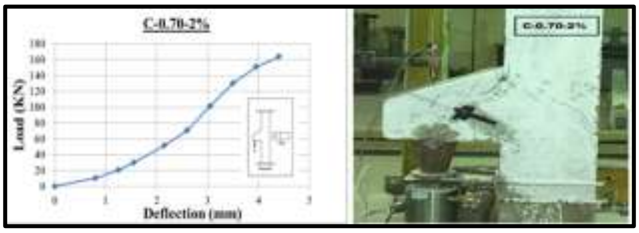

Figure 8: Specimen (C-0.70-2%)

The below graph indicates load deflection curve for C-0.65-2%. Here the first crack occurs at load-115.0KN, deflection of 7.43 mm and the ultimate load is 173.69 KN with deflection of 3.08mm.Figure-9

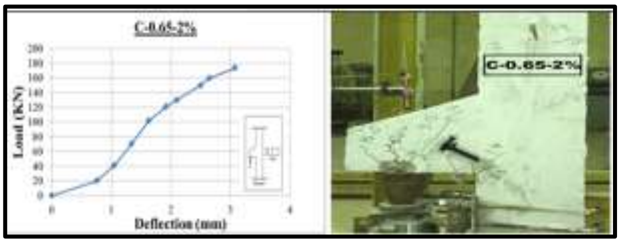

Figure 9: Specimen (C-0.65-2%)

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This Figure-10 shows all load deflection curves with constant span to depth ratio (a/d) =0.80 and variable volume fiber ratio (Vf %) (1% ,2% and 3%) that can appear the effect of fiber ratio on corbels increase from (11.7 % to 29.8 %) in ultimate load when using 1% and 2% fiber ratio respectively but decrease from (29.8% to 13.3%) in ultimate load when increasing volume fiber ratio to (3%).Increasing deflection when using fiber ratio (1%) is (18.9%) and decrease to (4% &3%) with increasing fiber ratio (2% &3%) respectively. That the same occur in first crack pattern (10% , 80% and 40%).

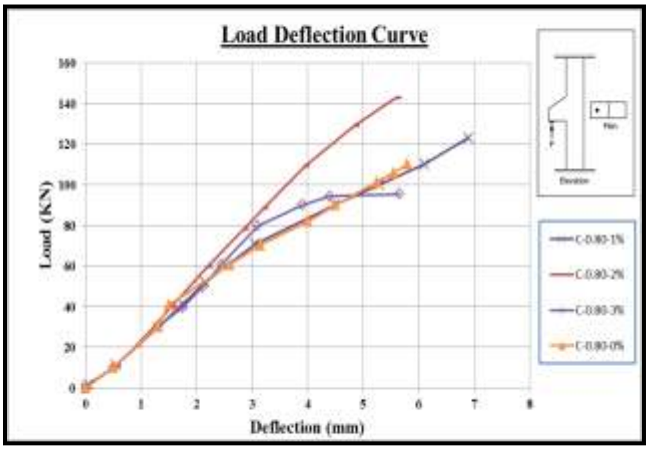

Figure 10: All Load Deflection Curves

This Figure-11 shows all load deflection curves with variable span to depth ratio (a/d) = (0.80,0.75,0.70 and 0.65) and constant volume fiber ratio (Vf %) = (2%) that can appear the effect of fiber ratio on corbels increase (1.5 %) in ultimate load when using span to depth ratio (a/d) =0.75 but decreasing deflection to (12%).and increasing of ultimate load (14%) addition to decreasing of deflection (21%) this case the same of specimen with span to depth ratio (a/d) =0.65 with increasing (21%) of ultimate load with decreasing deflection to (45%.)

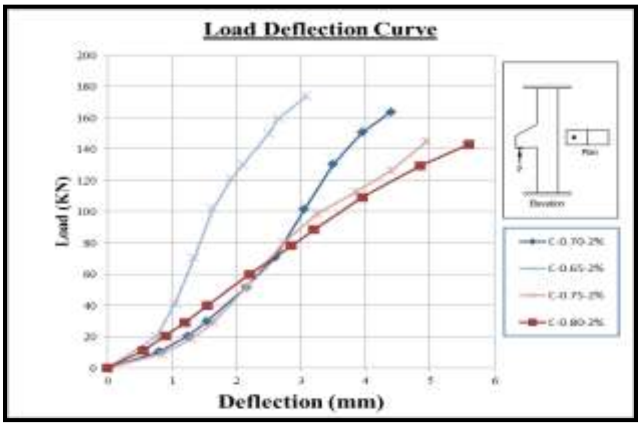

Figure 11: All Load Deflection Curves

Comparison between Experimental and Predicted Ultimate Loads:

Many equations have been suggested to evaluation the ultimate strength of reinforced concrete corbels. Among them, Fattuhi equation [13] and the ACI code [14].

These equations can concisely present as follows:

a) ACI code equation [14]

The ACI current design produces for corbels were base dons hear friction n empirical relationship based on the flexural capacity of the section. The smallest of the three values issued for design. The three basic equations allowed for design of the corbels by ACI-318 are given as follows.

- Shear friction strength:

$$V_u = \phi \mu A_v f_y \quad (1)$$

- Flexural strength:

$$V_u = \frac{M_u}{a} \quad (2)$$

$$M_u = \phi \mu A_{sm} f_y \left(d - \frac{A_{sm} f_y}{1.7 f_c' b}\right) \quad (3)$$

- Maximum shear strength:

$$V_u = 0.2 f_c' bd \quad (4)$$

Where:

V_u = corbel strength (N),

ø = strength reduction factor (assumed to be 1.0),

μ = coefficient of friction (assumed to be1.4formonolithicconcrete),

A_v = area of reinforcement extending across the critical section (mm^2),

F_y = yield strength of the main reinforcement (N/mm^2),

M_u = flexural moment (N.m),

a = shears pan length (mm),

b = width of corbels (mm),

f_c' =cylinder compressive strength (N/mm^2),

d = overall depth of corbel (mm).

In using the above equations, cylinder compressive strength of concrete fc is required. For the reason that fc' was not directly available from the tests, the following conversion formula proposed by Neville [15] was employed.

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$$f_c' = [0.76 + 0.2 \log_{10}(\frac{f_{cu}}{19.59})] f_{cu}$$

b) Fattuhi equation [13]

The predicted values are obtained by using the following modified shear- friction equation suggested by Fattuhi [13]

$$V_u = \phi(\eta A_{vf} f_{fu} \mu) + \phi (A_{vf} f_y \mu) \quad (6)$$

Where:

H = overall fiber efficiency factor=0.1,

A_{vf} = total area of fiber at critical section (mm^2),

F_{fu} = ultimate tensile strength of the fiber (N/mm^2),

ϕ = strength reduction factor (assumed to be1.0),

μ = coefficient to friction (assumed to be1.4 for monolithic concrete),

f_y = yield strength of the main reinforcement (N/mm^2).

TABLE III
Corbels results and comparison between experimental and predicted

Corbels I.D.	Experimental Results					Predicted Ultimate Loads			
	P_{cr}	Δ_{cr}	P_u	Δ_u	Mode of Failure	ACI code equation [14]		Fattuhi equation [13]	
	(KN)	(mm)	(KN)	(mm)		Pu (KN)	Exp./Pre.	Pu (KN)	Exp./Pre.
C-0.80-0%	50	2.6	110.15	5.8	D.S.	113.90	0.97	113.90	0.97
C-0.80-1%	55	3.1	123.08	6.9	C.S.	113.90	1.08	134.90	0.91
C-0.80-2%	90	3.5	143.01	5.6	F.S.	113.90	1.26	155.90	0.92
C-0.80-3%	70	4.1	95.51	8.6	D.S.	113.90	0.84	176.90	0.54
C-0.75-2%	80	2.1	145.06	4.95	D.S	113.90	1.27	155.90	0.93
C-0.70-2%	60	2.3	163.74	4.40	F.S.	113.90	1.44	155.90	1.05
C-0.65-2%	115	1.4	173.71	3.08	D.S.	113.90	1.52	155.90	1.11

V. CONCLUSION

Following conclusions are draw based on the results discussed in the previous topic

- The inclusion of short steel fibers in concrete mix provides effective shear reinforcement in corbels and provides better crack control in corbels.
- Both the first crack strength and ultimate strength in shear increase for fiber reinforced corbels because of their increased resistance to propagation of cracks.(Illustrated in Figure-10)
- For all the corbels were tested in this program, maximum shear strength was observed in corbels reinforced with 1.0 % and 2.0 % steel fibers followed by corbels containing reinforcement
- The presence of high percentage of fibers and/or horizontal stirrups transformed the mode of failure of the tested corbels into a more ductile one and increased the number of diagonal cracks. Table-III

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All thanks and appreciation for the support of this research professor Amin Saleh and my friend engineer Mamoud Rehab.

NOTATION

The following symbols are used in this paper:
Avf1 = area of fibers at column-corbel junction mm2;
Avf2 = area of main bars and stirrups at column-corbel junction mm2;
a = shear span mm;
b = total width of rectangular section mm;
d = effective depth to main bars mm;
fct = average splitting tensile strength of concrete MPa;
fcu = average cube compressive strength of concrete MPa;
ffu = ultimate tensile strength of fiber MPa;
fy = yield strength of main bars or stirrups MPa;
h = overall depth of a corbel at column-corbel junction mm;
Vcal = calculated shear resistance (strength) of a corbel N;
Kxp = experimental shear resistance (strength) of a corbel A';
Vn = nominal shear strength of a corbel N;
Vnl = shear resistance of fibers N;
Vn2 = shear resistance of main bars and stirrups N;
Vu = factored shear force N;
η = overall fiber efficiency factor;
μ = coefficient of friction;
ρ = ratio of main bars (i.e., area of main bars/overall area of concrete); and
ϕ = strength reduction factor;
Pcr. =cracking load;
Pu. = ultimate load;
Δcr = deflection at cracking load;
Δu = deflection at ultimate load;

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